CCNF-810865--3

LA-UR -81-2500

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MASTER

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SUBMITTED TO: Solar World Forum
Brighton, England
August 23-28, 1981

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UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

A PASSIVE-SOLAR RETROFIT STUDY FOR THE UNITED STATES NAVY+

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ABSTRACT

A passive solar retrofit study has been conducted for the United States Navy at the Los Alamos National Laboratory. The purpose of the study was to determine the energy savings obtainable in concrete block buildings from several passive solar heating strategies. A procedure involving the use of test cell data and computer simulation was employed to assess the merits of six retrofit options. The six strategies selected were chosen on the basis of providing a series of options that will deliver increasing energy savings at the cost of correspondingly increased levels of commitment.

KEYWORDS

Passive solar heating retrofit; direct gain; thermal storage wall; concrete block.

INTRODUCTION

Many US Navy office buildings and living quarters are constructed with concrete block walls and poured concrete floor slabs. The massive nature of these buildings makes them prime candidates for the application of passive solar space heating retrofits because the structures have enough inherent heat capacity to effectively store and utilize large quantities of solar energy. The present study was initiated in order to assess the merits of several retrofit strategies and to compare those strategies with simple addition of insulation to either the inner or outer surface of the block walls. The results obtained are applicable to south-facing block walls or block walls that depart from true south by no more than 30° to the east or west. The optimum orientation for passive solar space heating is generally close to true south but penalties are small (less than 5%) for deviations of up to 30°. Our results indicate that employing passive solar strategies on south-facing block walls is preferable to the use of insulation, which, under some conditions, can actually increase the building heat load.

+This work was performed under the auspices of the US Navy Civil Engineering Laboratory.

TYPICAL CONCRETE BLOCK NAVY BUILDING

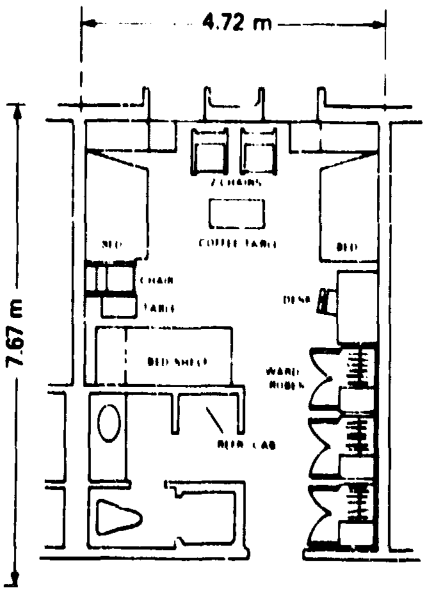
The floor plan of a room in a typical Navy B.E.Q. (Bachelor Enlisted Quarters) of concrete block construction is presented in Fig. 1. The building itself is generally 2 to 3 stories high and may contain 10 to 20 of these rooms on each floor, as well as additional common areas for lounges, concessions, etc. The external walls are constructed of 0.203 m concrete building blocks, and the floors are poured concrete slabs, 0.152 m thick on the ground level and 0.102 m thick on the upper levels. The interior partitions are generally of lightweight construction, and the windows are single glazed.

The experimental and computational phases of the analysis reported in the paper are based on the behavior of a single south-facing zone that is thermally coupled to other zones in the structure by a forced air heat distribution system. The building thermal factor is approximately 261 kJ per heating degree day (^{o}C) per m^2 of floorspace (kJ/DD m^2). Thus, a single 36.2 m^2 zone experiences a heat load of 9448 kJ/DD.

The exterior wall area of the zone (assumed to be south facing) is 11.5 m^2 of which about 2.23 m^2 is taken by windows. This entire south-facing surface can be considered a solar collector that may be efficient or inefficient, depending on the treatment of the wall.

TEST CELL EXPERIMENTS

Two adjacent instrumented passive solar test cells were used to provide a source of data for validating computer models of a typical concrete block building and the various retrofit options considered in this study. The cells are about 1.52 m wide, 3.04 m high, and 2.44 m deep. Construction is 0.1 m stud frame (except for the south wall) with fiber glass batts in the cavities and 0.0254 m of polystyrene foam insulation on the inside surfaces. Solid concrete blocks were placed on the floor and suspended from the ceiling on a metal rack to represent the concrete floor slabs present in the actual building. A fixed infiltration rate of two air changes per hour was induced by a blower in order to increase the heat load of the cells and simplify the analysis of infiltration heat transfer. Electric light bulbs with a total power of 1 kW were placed in each test cell as a source of auxiliary heat. The light bulbs were thermostatically controlled by the HP 9845 data acquisition system that limited the globe temperatures of the enclosures to a minimum of 24^{o}C.



NET LIVING AREA = 25.1 m^2

GROSS AREA = 36.2 m^2

Fig. 1. Floor plan of typical room.

The south wall of one of the test cells (cell 10) used in this project was constructed to represent a typical Navy concrete block building and was maintained in that fixed reference configuration throughout the test period. Concrete building blocks with nominal dimensions of 0.203 m by 0.203 m by 0.406 m were set in place and carefully sealed at the edges. One single-glazed window with a width of 0.635 m and a height of 0.866 m was centered laterally on the wall with the lower edge about 1.22 m above the bottom of the block wall. The block wall was painted beige, a color frequently used on Navy buildings. The measured solar absorptance of the beige blocks was 0.60.

The second test cell (cell 9) was originally configured to be identical to the reference cell, and globe temperatures were monitored to insure that, for all practical purposes, the two cells were equivalent. Next we introduced a series of six retrofits on cell 9. These modifications and the test period for which they were in place are given below:

Cell 9A (Feb. 10-16). The window was double glazed with a 0.0127 m air gap between glazing layers.

Cell 9B (Feb. 18-23). The exterior surface of the block wall was painted dark brown. The measured solar absorptance of the dark brown blocks was 0.90.

Cell 9C (Feb. 25-Mar. 2). The double-glazed window and dark brown paint were left in place and a 0.0508 m-thick layer of polystyrene board insulation was bonded and sealed on the inside surface of the block wall.

Cell 9D (Mar. 7-16). The polystyrene was removed from the inside surface of the block wall. The block wall was converted to an unvented Trombe wall by placing a layer of acrylic Exolite glazing two in. from the outer surface. Exolite is a double-walled material with connecting webs that form rectangular channels that are roughly 0.0127 m square.

Cell 9E (Mar. 19-25). The Exolite glazing was removed and the outer surface of the block wall was covered with a 0.0508 m-thick layer of polystyrene board insulation. The polystyrene was painted beige.

Cell 9F (Mar. 30-Apr. 13). The polystyrene insulation was removed from the outer surface of the block wall and replaced with a selective absorber manufactured by Berry Solar Products. The Berry foil consists of chrome oxide (black chrome) deposited on 8.89×10^{-5} m-thick copper sheet. Devcon epoxy cement was used to bond the foil to the concrete block surface. The Exolite glazing was then placed over the Berry foil, leaving an air gap of 0.0508 m to form a selective absorber Trombe wall.

Test cell data was used to validate a computer model called SUNMIX for each of the configurations described above. SUNMIX is capable of simulating the response of mixed direct gain/thermal storage wall buildings and is based on an earlier computer model called SUNSPOT (Wray, 1980).

SIMULATION ANALYSIS AND RESULTS

Having validated the SUNMIX computer model for the typical Navy concrete block building and the six retrofit options, annual performance calculations were performed for building sites in San Diego, Charleston, and Boston. A major Navy base is located in each of these cities. San Diego has a very mild climate with a January Q_v/DD ratio of 2,778 kJ/m^2 DD, where Q_v is the total insolation on a vertical surface and DD is the 18.3°C base heating degree days. The high Q_v/DD ratio observed in San Diego indicates that a lot of sunshine is available to meet the relatively small heat load. In the moderate winter climate of

Charleston, the January Q_V/DD ratio is 1,287, and in Boston, where the winters are severe, the Q_V/DD ratio drops to 511 in January. Thus, the three selected locations provide a range of climate types in which to test the retrofit designs.

The relative solar savings fraction (RSSF) of each of the six retrofit designs is plotted in Fig. 2 for each of the three representative cities. The RSSF is defined as the energy saved by a particular retrofit configuration relative to the original unmodified Navy design. Thus, if $QAUX_{10}$ represents the auxiliary heat required by the original building and $QAUX_N$ is the heat required by the Nth retrofit, then the RSSF of the Nth retrofit is

$$RSSF = \frac{QAUX_{10} - QAUX_N}{QAUX_{10}} .$$

The symbols 9A, 9B, 9D, 9E, and 9F represent retrofit designs that correspond to the test cell configurations that were tested during the winter of 1981 at Los Alamos. Retrofit design 9G is the same as test cell 9C, except that the outer block wall color was changed from dark brown to beige so that the effect of insulation on the interior surface of the block wall could be isolated.

Note first from Fig. 2 that retrofit 9A, for which the windows on the south wall were double glazed, yields small energy savings that, as one would expect, increase with the severity of the climate. The observed energy savings are not large because the window area for the Navy buildings is small, totaling only about 6% of the gross floor area.

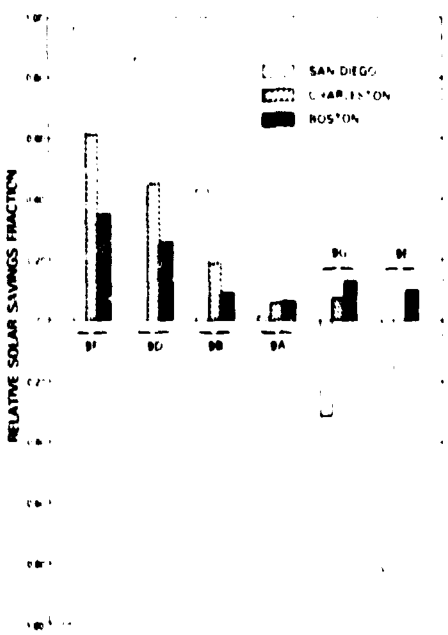


Fig. 2. Performance of six retrofit designs in three representative cities.

Next consider retrofit 9B, which is identical to 9A except that the block wall has been painted dark brown yielding a solar absorptance of 0.90 compared to 0.60 for the original beige wall. Only a modest gain is realized in the cold and cloudy Boston climate, but the improvement in both Charleston and San Diego is quite significant. Since dark brown paint costs no more than beige paint, the incremental cost of retrofit 9B compared to 9A is zero, making 9B very attractive on the basis of economics as well as performance.

Retrofit 9D is obtained by adding double-walled Exolite glazing to configuration 9B. A 0.0508 m air gap was allowed between the block wall and the inner surface of the Exolite. This retrofit improved performance dramatically in all three cities, but, unlike the previous case, the incremental cost will be significant.

Finally, the best performance is achieved in retrofit 9F for which the dark brown paint of 9D was replaced by Berry foil, a selective absorber. Performance is moderately improved in all three cities.

Let us return now to retrofit 9A, the configuration with double-glazed windows, and introduce conservation features rather than passive solar features. Retrofit 9G is identical to 9A, except that 0.0508 m of polystyrene board insulation has been placed on the inner surface of the block wall. The results are (a) 30% more auxiliary heat than required by the reference design is needed in San Diego, (b) performance is slightly improved in Charleston, and (c) energy savings are doubled in Boston relative to 9A. These results indicate that insulating the inner surface of south-facing block walls is detrimental in warm, sunny climates and is of little value in colder, cloudy climates. The passive solar options exhibit much greater potential for energy savings.

Now for one final experiment, we take the insulation from the inside surface of the block wall in retrofit 9G and place it on the outside surface to obtain retrofit 9E. The board insulation is painted the same beige color as the exterior of the block wall that is now covered. Note from Fig. 2 that introduction of this modification would be a serious error. In San Diego the RSSF has dropped to a negative 84%, indicating that we will now have to provide 84% more heat than was required by the original unmodified Navy building. In Charleston the RSSF has dropped to zero, and in Boston the energy savings is slightly reduced from that observed for configuration 9G, which had insulation on the inner surface of the block wall. The general rule is that insulation should never be placed on the outside surface of south-facing block walls. In mild climates, any insulation on the south wall is detrimental to performance, and in moderate to severe climates, insulation on the inside surface yields small energy savings that exceed those obtainable by insulating the outside surface. Insulation on the outer surface of south-facing mass walls negates solar gains that might otherwise occur, and the penalty for negating those gains is severe in sunny climates and small in cold, cloudy climates.

CONCLUSIONS

Double glazing the windows in concrete block buildings is an effective means for reducing energy consumption for space heating. The amount of energy saved depends on the window area and the severity of the winter climate.

The progressive addition of dark brown paint, Exolite glazing, and Berry selective absorber foil to the south-facing side of concrete block buildings yields corresponding reductions in energy consumption for space heating. The use of insulation on south-facing concrete block walls is either harmful or of little value except in severe winter climates. When such insulation is used, it should always be placed on the inner surface of the block wall. An exception to the rule might arise if a building experiences high levels of direct gain heating, but that is a subject requiring additional research.

ACKNOWLEDGEMENTS

Claudia Kosiewicz provided programming support for the duration of the Navy passive solar retrofit project, and Lois Murray and Jan Sander typed this paper. Their help is greatly appreciated.

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